

# SINGLE AND COMPOSITE HOT SUBDWARF STARS IN THE LIGHT OF 2MASS PHOTOMETRY

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**Abstract.** Utilizing the Two Micron All Sky Survey (2MASS) All-Sky Data Release Catalog, we have retrieved useful near-IR  $J$ ,  $H$ , and  $K_S$  magnitudes for more than 800 hot subdwarfs (sdO and sdB stars) drawn from the *Catalogue of Spectroscopically Identified Hot Subdwarfs* (Kilkenny, Heber, & Drilling 1988, 1992). This sample size greatly exceeds previous studies of hot subdwarfs.

We find that, of the hot subdwarfs in Kilkenny et al.,  $\sim 40\%$  in a magnitude limited sample have colors that are consistent with the presence of an unresolved late type (FGK) companion. Binary stars are over-represented in a magnitude limited sample. In an approximately volume limited sample the fraction of composite-color binaries is  $\sim 25\%$ .

**Keywords:** binaries, early-type stars, horizontal branch stars, subdwarfs, infrared

O star... Say something to us we can learn...  
Say something! And it says, "I burn." ...  
—Robert Frost

## 1. The Sample and Data Collection

We studied hot subdwarf stars listed in the *Catalogue of Spectroscopically Identified Hot Subdwarfs* (Kilkenny et al., 1988) as updated in an electronic version by Kilkenny, c. 1992 (hereafter KHD). Details of the data collection and analysis procedure for a sub-sample from the 2MASS 2<sup>nd</sup> Incremental Data Release can be found in Stark & Wade (2003). In the current study we had improved coordinates for 1486 objects (excluding 15 duplicates), while 26 objects remained unrecovered and are not included. We recovered 2MASS All-Sky counterparts for 1247 objects, 831 of which are hot subdwarfs with *both*  $J$  and  $K_S$ .

For use in comparison, near-infrared colors for Pop I main sequence (MS) stars (Bessell & Brett, 1988; Johnson, 1966) were transformed to the 2MASS  $JHK_S$  system using relations given in the *Explanatory Supplement to the 2MASS All Sky Data Release*<sup>1</sup>.

<sup>1</sup> <http://www.ipac.caltech.edu/2mass/releases/allsky/doc/explsup.html>



Table I. Binomial fractions of single and composite-color subdwarfs observed by 2MASS.

Group	MLS		VLS	
	Single	Composite	Single	Composite
sdB	$55 \pm 4\%$	$45 \pm 4\%$	$72 \pm 4\%$	$28 \pm 4\%$
sdO	$67 \pm 6\%$	$33 \pm 6\%$	$82 \pm 6\%$	$18 \pm 6\%$
Total	$58 \pm 3\%$	$42 \pm 3\%$	$75 \pm 3\%$	$25 \pm 3\%$

## 2. A “Volume Limited” Sample

Since 2MASS is a magnitude limited survey, 2MASS-KHD is a magnitude limited sample (MLS). In a MLS, *composite subdwarfs are overrepresented* (the presence of a late type companion increases the distance to which a composite remains brighter than the limiting magnitude). We made a cut in the  $(K_S, J-K_S)$  color-magnitude diagram to define a *statistical* volume limited sample (VLS), by removing composite subdwarfs that would not have been detected if they were single. Stark & Wade (2003) discuss this process in detail (however, the cut made in the current study was updated and is thus slightly different).

## 3. Color Distribution

We focused on  $J-K_S$ ,  $V-K_S$ , and  $B-V$ . Single hot subdwarfs mainly are found in a region defined by:  $B-V \lesssim +0.1$ ,  $V-K_S \lesssim +0.2$ , and  $J-K_S \lesssim +0.05$ . Reported composite hot subdwarfs have redder colors than single subdwarf stars (most notably in  $J-K_S$ ).

Figure 1 shows the distribution in  $J-K_S$  for: the MLS (panel *a*) and the VLS (panel *b*). Both plots reveal a bimodal distribution (in both the total and sdB only sub-sample) with peaks at:  $J-K_S \approx -0.15$  ( $\sim$ B3 spectral type) and  $+0.30$  ( $\sim$ G0 spectral type). Assuming stars within the blue peak ( $J-K_S \lesssim +0.05$ ) are single stars (or sd+WD pairs, with colors indistinguishable from single hot subdwarfs), and stars in the red peak ( $J-K_S \gtrsim +0.05$ ) are composite (sd+late type) systems, then we obtain the binomial fractions of single and composite-color systems observed by 2MASS in KHD given in Table I.

The bimodal distributions of sdB stars alone can be fit as the sum of two Gaussians (parameters Table II, fits Figure 1*c-d*). We find that the Gaussian areas are consistent with the binomial fractions from a cut at  $J-K_S = +0.05$ . The dispersions of both blue Gaussians, and the

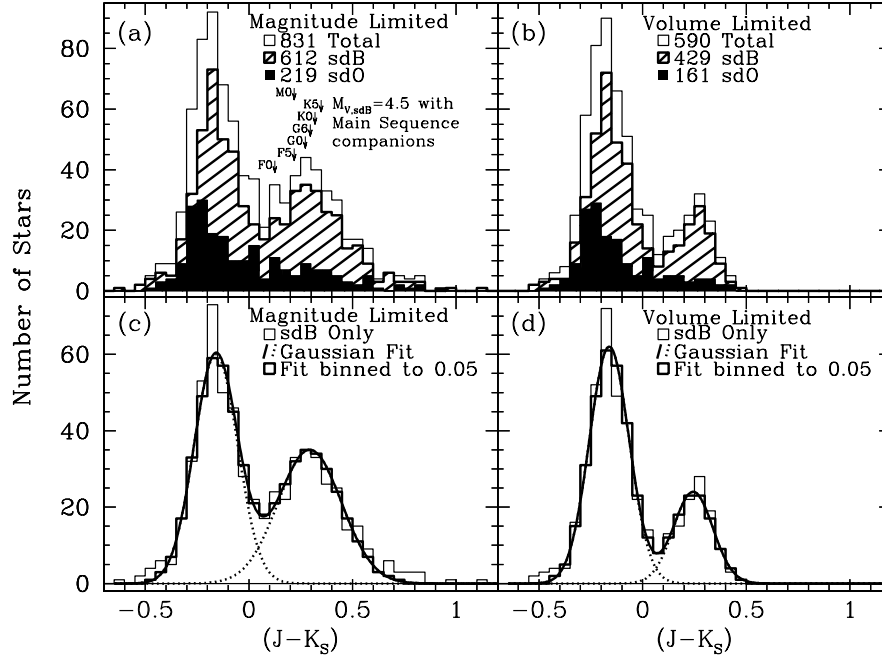


Figure 1. Bimodal distribution of  $J-K_S$ . Panel *a* also shows the composite  $J-K_S$  colors of sdB+MS stars assuming  $M_V = 4.5$  and  $J-K_S = -0.15$  for the sdB. Panels *c* and *d* show the Gaussian fits to the sdB only distributions.

VLS red Gaussian, are consistent with the average 2MASS photometric error [ $\sigma(J-K_S) \approx 0.1$ ], implying there is little intrinsic spread in  $J-K_S$  of single sdBs or the VLS late type companions.

Table II. Parameters for the Gaussian fits (Figure 1c-d).

Parameter	MLS		VLS	
	Blue	Red	Blue	Red
Center	-0.159	+0.294	-0.161	+0.244
Amplitude	60	35	62	24
Dispersion	0.105	0.153	0.096	0.095
Area Proportion	54 : 46		72 : 28	
Integral of Fit	584		413	
$\chi^2$ , $\chi_R^2$ (DOF)	20.67, 1.03 (20)		11.96, 0.80 (15)	

The strongly *bimodal* distribution in  $J-K_S$  also indicates there are no (or few) companions that are dM, or  $\sim$ F0 and earlier in KHD. In Figure 1a, the  $J-K_S$  values of sdB+MS composites are indicated assuming  $M_{V,\text{sdB}} = 4.5$  and  $(J-K_S)_{\text{sdB}} = -0.15$ . Companions of type F0 and earlier or M0 and later would fall in the gap between the two peaks. If a significant population of such companions existed, the area between the peaks would have been filled with their composites.

#### 4. Concluding Remarks

The KHD catalog itself is likely *not* representative of the true hot subdwarf population. There are completeness issues, including varying magnitude limits and classification criteria used by KHD's sources. Yet, since KHD is the most complete single compilation of field hot subdwarfs available, we analyzed it despite its weaknesses. Current and future surveys should result in a more complete census of hot subdwarfs.

In KHD, we find  $\sim 40\%$  MLS ( $\sim 25\%$  VLS) of the subdwarfs are consistent with having unresolved late type companions of spectral types late F–K. However, from these data alone we cannot determine evolutionary states (MS and/or subgiant) unambiguously for these companions, nor whether they interacted with the progenitor.

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